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Nigeria biogas potential from livestock manure and its estimated climate value

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ABSTRACT

This paper estimates Nigeria biogas potential from livestock manure and its contribution to climate change mitigation. Findings reveal that Nigeria biogas potential from livestock manure represents a minimum of 1.62×10^9 m^3 of biogas per annum. Replacing diesel fuel with methane derived from biogas to produce electricity as well as inorganic nitrogen fertilizer with organic nitrogen from the anaerobic digester for agricultural use will lead to carbon dioxide (CO_2) emission savings of 683,600 t per annum. This amount represents the minimum contribution of biogas derived from livestock manure to climate change mitigation if harnessed for electricity and agricultural use in Nigeria.

Contents

1. Introduction 243
2. Data collection and analysis 244
3. Results and discussion 245
   3.1. CO_2 emission savings from electricity generation 245
   3.2. CO_2 emission savings from agriculture 245
4. The challenges 246
5. Conclusions and recommendations 247
References 247

1. Introduction

Both Rio [1] and Copenhagen [2] stress the need to cut global emissions, while Intergovernmental Panel on Climate Change (IPCC) [3] points out that an increase in greenhouse gas concentrations due to anthropogenic activities will result in the warming of the earth's surface. Specifically, the Cancun Agreements consider limiting the global average temperature to below 2.0 °C [4,5]. Worldwide, the human induced emissions of greenhouse gases have been increasing, and the growing use of fossil fuels since 1850 has led to a rapid growth in carbon dioxide (CO_2) emissions [4]. On the other hand, the earth's average temperature is projected to increase from 1.4 to 5.8 °C between 1990 and 2100, while the global average sea level is expected to rise from 9 cm to 88 cm over the same period [6,7]. Consistent with trends in other countries, CO_2 emission in Nigeria is increasing. It increased from 3.41×10^6 in 1960 to 70.23×10^6 t (tonnes) in 2009 [8]. As a result of emission impacts, agreements and protocols to limit air pollutant emissions of which CO_2 is one have been established – for example, the United Nations Framework Convention on Climate Change (UN FCCC) Kyoto Protocol [9].

Although the short to medium-term burden of climate change mitigation clearly rests on the shoulders of the Annex 1 countries, in the face of socio-economic improvements and population

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growth in other countries, efforts to abate future greenhouse gas emissions from these countries will also be needed if global atmospheric greenhouse gas emission levels are to stabilize or reduce. For example, it is projected that Africa will contribute between 1107 and 1852 $\times 10^6$ t of CO_2 from 2010 to 2035, which is growing at an average of 1.8 per cent per annum [10]. Although Nigeria, which belongs to the non-Annex 1 countries, is not required to take any abatement action now under the UN FCCC Kyoto Protocol [9], the impact of climate change is a crucial issue for Nigeria and the Federal Government has recognized the country's vulnerability to increased climate change. For example, about 70 per cent of the Nigerian population depend on agriculture to meet their daily livelihoods which could be affected by climate change [11]. Globally, the livestock production sector is responsible for 18 per cent of the overall greenhouse gas emissions [12]. According to Tauseef et al. [13], livestock manure contributes about 240 $\times 10^6$ t of CO_2-equivalent of methane to the atmosphere. However, there is a growing understanding that climate change will affect water quality, water quantity and water use [14,15], and also increase the risk of desertification [16]. Generally, water use, both domestic and agriculture, will rise with an increase in temperature which could have a negative impact on rain-fed farming in most rain dependent developing countries, while desertification is also a potent threat to agriculture. This implies that human livelihoods that are dependent on rain are intricately vulnerable to climate impacts [17,18]. Amidst all of these threats, the global freshwater withdrawal is expected to rise by 25 per cent by 2030 due to population growth [15].

At present, grid electricity supply in Nigeria is highly erratic. And there are cases of outages of up to 20 h a day in some localities. This situation has necessitated the call for sustainable solutions to rescue the irregular grid power situation in Nigeria in the face of growing demands. Nigeria, with a population of 162,470,737 in 2011 [8], has 5900 mega watts (MW) of installed generating capacity with grid power supply hovering around 3000 MW on an annual average in recent times. Peak demand has been estimated at over 11,500 MW, while grid power generation was as low as 1500 MW in the year 2000 [19]. To boost grid power supply the Federal Government injected about N5 trillion (US$31.45 billion) between 1999 and 2013, while grid electricity generating capacity increased from 2000 MW in 1999 to 4500 MW in 2013 [20]. In order to meet a minimum electricity demand during grid power failures in the country, most households and business organizations rely on stand-alone petrol and/or diesel fuel generators. Electricity from these sources is estimated to contribute over 6000 MW [19]. As of 2011, about 70 million generators are estimated to be in use in Nigeria, while between 60 and 70 million people in Nigeria are not connected to grid electricity or lack access to grid supply [21]. It is estimated that Nigerians spend about US$8 billion a year running the diesel generators, and the country is the largest market for generators in Africa [22]. Forecast indicates an average growth rate of 8.7 per cent per annum for generators which will drive up market volume from N71.55 billion (US$450 million) in 2011 to N151.16 billion (US $950.7 million) by 2020 [23].

However, that biogas is derived from the anaerobic digestion of organic substrates has been well illustrated in the literature (see, e.g., Al-Maliky [24], Ciotola et al. [25], Akbulut [26], Pipatmanomai et al. [27], Mohseni et al. [28], Lapp et al. [29], Bond and Templeton [30] and Tauseef et al. [13]). Essentially, anaerobic digestion consists of the decomposition of organic materials in the absence of oxygen and this process produces biogas which is rich in methane, followed by carbon dioxide, ammonia and traces of other gases, volatile fatty acids, and water. To produce electricity, many options exist. For example, the anaerobically generated (dry) biogas can be fed directly into a gas-fired combustion turbine. The combustion of biogas converts the energy stored in the bonds of the molecules of methane contained in the biogas into mechanical energy. The mechanical energy produced by biogas combustion in the engine spins the turbine that produces electricity [31]. Alternatively, carbon dioxide, water, hydrogen sulfide, nitrogen, ammonia, siloxanes, particulates and other gases can be removed from biogas to retain bio-methane for direct use in internal combustion engines to produce electricity [32]. According to von Mitzlaff [33], these unwanted gases and water do not participate in the combustion process; instead, they absorb energy from the combustion process thereby leaving the process at a higher temperature. This is consistent with the observation of Lapp et al. [29] who assert that carbon dioxide generally reduces the heat content of fuel. In general, the anaerobic digestion of organic materials (or substrates) in biogas digesters gives two main outputs: biogas and bio-manure [34,12,35].

Since efforts to cut global greenhouse gas emissions are now everybody's and every nation's business, this paper examines the amount of CO_2 that could be avoided in Nigeria by replacing diesel fuel-powered electricity generator with methane derived from biogas. It also takes a look at the amount of CO_2 emissions that could be saved if inorganic nitrogen fertilizer is replaced with spent bio-manure or digestate from the anaerobic biogas digester. This paper focuses on CO_2, because it is the most significant greenhouse gas emission that makes up nearly 77 per cent of global greenhouse gas emissions [36]. However, the literature (e.g., Sieling et al. [37], Igliński et al. [38], Asam et al. [39], Holm-Nielsen et al. [12], Ciotola et al. [25], Melikoglu [40], Huopana et al. [41] and Katuwal and Bohara [42]) agrees that harnessing energy from renewable sources could contribute to climate change mitigation. Apart from its utilization for electricity and heat production [27,29,43,30,44,45,32,35], biogas can also replace fossil fuels in the transport sector (e.g., in 2009, Sweden had about 15,000 vehicles driving on bio-methane [12]), serve as lamp fuel (e.g., biogas was used to power street lights in Exeter (UK) in 1895 [38,46]) and cooking fuel [47,29,48,30,49,50,44,35].

The rest of this paper is organized as follows: The approach to data collection and analysis is described in Section 2. Results are presented and discussed in Section 3. The challenges to realising the potential benefits of biogas for electricity generation and agricultural use in Nigeria are presented in Section 4. This is followed by conclusions and recommendations in Section 5.

2. Data collection and analysis

Secondary data on the domestic livestock population in Nigeria were obtained from FAOSTAT production database of the Food and Agriculture Organization of the United Nations in March 2013 for the period 2000–2011 [51]. The average value, which will be used in the rest of this paper, is estimated at: cattle 15,997,567; poultry (chickens) 155,630,670; goats 50,569,783; pigs 6,369,286 and sheep 32,158,042. Data on the minimum value of biogas yield per livestock were obtained from Adeoti et al. [52] as follows: cattle 78×10^{-3} m^3/day/livestock, poultry 1.54×10^{-3} m^3/day/livestock, goat and sheep 31×10^{-3} m^3/day/livestock, and pigs 59×10^{-3} m^3/day/livestock.

To estimate the amount of CO_2 emissions from diesel generators, this paper utilizes an emission factor of 2.6 kg CO_2 per litre of diesel fuel (from the calculation that diesel fuel contains about 0.695 kg of carbon). Since not all the carbons in the diesel fuel will be oxidized into CO_2 due to engine conditions, the emission factor (2.6 kg of CO_2) was adjusted to account for a small portion of the fuel that will not be oxidized into CO_2. In this paper, the oxidation factor used is 0.90 to obtain an average emission value of 2.34 kg of CO_2 per litre of diesel fuel. However, it should be noted that the

emission values are based only on the average carbon content of conventional diesel fuel, and do not include the CO_2 emissions of fuel additives such as biodiesel and others. In the refining of diesel fuel, for a refinery operating at an average of 88.5 per cent refining efficiency, about 0.26 kg of CO_2 will be emitted per litre of diesel fuel produced [53]. Therefore, the total CO_2 emission translates to 2.60 kg of CO_2 per litre of diesel fuel. Based on 100 per cent conversion of fuel carbon to CO_2, one litre of diesel fuel has an energy content of 9.8 kW h on the average (see also Biomass Energy Centre [54]). Considering a diesel generator efficiency put at an average of 30 per cent, one litre of diesel fuel will generate 3 kW h of electricity. Therefore, the total CO_2 emissions from diesel fuel-powered generator translate to 0.87 kg per kW h.

In the case of biogas, its proportion of methane is not fixed. For example, the literature has reported between 40 and 70 per cent [55–57], 40 and 75 per cent [31], 50 and 70 per cent [26,30,35], or between 55 and 80 per cent [27]. However, due to the absence of data in the case of Nigeria, a methane content of 60 per cent has been used, and 1 m^3 of bio-methane when combusted will generate about 1.85 kg of CO_2 based on the average carbon content of methane. In terms of energy content, at 100 per cent conversion of fuel carbon to CO_2, 0.1 m^3 of bio-methane will generate about 1 kW h of heat energy [58], although GTZ [55] and Sasse [58] put the energy content of biogas at 6 kW h per m^3. Adjusting for unburned bio-methane of 0.01 after Ahlgren et al. [59] and Scholz et al. [60] (which translates to 9.7×10^6 m^3/annum, including leakages and slips), the average emission value becomes 1.83 kg of CO_2 per m^3 of bio-methane. Therefore, the amount of CO_2 emissions expected from bio-methane combustion to generate 1 kW h of electricity translates to 0.18 kg of CO_2. In the literature, the CO_2 proportion of biogas also varies. According to GTZ [55], Abdel-Hadi [56] and Werner et al. [57], it is between 30 and 60 per cent. Other scholars put it at between 25 and 40 per cent [31], 25 and 45 per cent [26], 30 and 40 per cent [35], 30 and 50 per cent [30], while Pipatmanomai et al. [27] put it at between 20 and 45 per cent. In this paper, it is assumed that the amount of CO_2 emitted during anaerobic digestion of livestock manure equals the amount captured by the parent plant during photosynthesis which remained in the manure before digestion. Therefore, its emission during biogas production translates to a net zero emission on the environment. This assumption is consistent with the suggestion of Wilkie [61], Akbulut [26], Ghafoori et al. [45], and IPCC [62]. These authors argue that the use of renewable resources, unlike fossil fuels, represents a closed carbon cycle and does not contribute to the increase in global concentrations of carbon dioxide. On the other hand, Mohseni et al. [28] assert that the CO_2 emitted during anaerobic digestion can be captured and recycled to produce additional methane through a process known as Sabatier reaction. Although this paper assumes a net zero emission on the environment, if the suggestion of Mohseni et al. [28] was followed, it would amount to further decarbonization of the environment. In this paper, the following upstream CO_2 emissions have not been considered. In the case of diesel fuel, these include the CO_2 emissions due to crude oil exploration and pre-processing, crude oil refinery construction, diesel fuel transportation and distribution to the final destinations, and diesel fuel generator manufacture, transportation and distribution to the final users. In the case of bio-methane, these include the CO_2 emissions due to biogas and bio-methane processing infrastructure construction, the collection and transportation of substrates (livestock manure) to biogas plants, the construction of bio-methane transport and distribution infrastructure, and bio-methane generator manufacture, transportation and distribution to final destinations. On a rough assessment, it is assumed that the aggregate sum of upstream CO_2 emissions resulting from diesel fuel use will be more than that of bio-methane looking at the net upstream processes required for diesel fuel production. This assumption is in agreement with the submission of IPCC [4]. IPCC [4] posits that under the lifecycle assessments of electricity generation, greenhouse gas emissions from renewable sources are significantly lower than those associated with fossil fuel options.

3. Results and discussion

3.1. CO_2 emission savings from electricity generation

Table 1 presents the estimated biogas potential from livestock manure in Nigeria. As shown in Table 1, Nigeria has a minimum biogas potential of 4.44×10^6 m^3/day, or 1.62×10^9 m^3/annum. Based on the 60 per cent assumption, the bio-methane proportion in the biogas is estimated at 0.97×10^9 m^3 per annum (see Table 2). Table 2 also shows the amount of CO_2 emissions from diesel-powered and bio-methane-powered generators. As illustrated in Table 2, about 2.90×10^9 kW h of electricity is expected to be generated from bio-methane under the various assumptions made. At an average of 6000 full load hours per year, this translates to 483 MW of electricity per year. Replacing diesel fuel with bio-methane, therefore, will lead to CO_2 emission savings of 0.68×10^6 t per annum and 0.97×10^9 l of diesel fuel saved per annum (Table 2).

3.2. CO_2 emission savings from agriculture

Svoboda et al. [63] and Quakernack et al. [64] assert that bio-manure from anaerobic biogas digester represents a valuable source of plant-available nutrients, which can be used in a sustainable manner to replace fossil fuel-based mineral fertilizers. Kongshaug [65] reports that fertiliser production consumes approximately 1.2 per cent of the global energy and also is responsible for approximately 1.2 per cent of the total greenhouse gas emissions. At present, there is no local inorganic fertilizer manufacturing companies in Nigeria. All the inorganic fertilizers being used in the country are imported from various countries. Due to the absence of recent data, the average nitrogen fertilizer consumption in Nigeria between 2002 and 2005 has been used to assess the amount of CO_2 that could be avoided if inorganic nitrogen fertilizers are replaced with bio-manure in Nigeria. According to Liverpool-Tasie et al. [66], Nigeria consumed 94,400 t of inorganic nitrogen fertilizers in 2002; 137,603 in 2003; 101,001 in 2004, and 115,041 in 2005; averaging 112,011 t of inorganic nitrogen fertilizer consumed over the period. At the field level, the mean fertilizer use in Nigeria has been estimated at 13 kg/ha [66]. However, Guster et al. [67] assert that inorganic and organic fertilizers differ markedly with regard to their transformation in soils and in the utilization of the applied nutrients by plants. Following the suggestion of Mahmoud et al. [68] that organic nitrogen from bio-manure can be used to replace around 25 per cent of inorganic nitrogen fertilizer without jeopardizing plant

Table 1
Livestock population (average) and their estimated biogas yield (minimum value).

Type	Livestock population (average)	Biogas yield ($\times 10^6$ m^3/day)
Cattle	15,997,567	1.25
Poultry (chickens)	155,630,670	0.24
Goats	50,569,783	1.57
Pigs	6,369,286	0.38
Sheep	32,158,042	1.00
Total		4.44

Table 2
Estimated CO_2 emissions from bio-methane- and diesel fuel-powered generators.

S/no.	Description	Amount
(a)	Annual biogas potential	1.62×10^9 m^3
(b)	Bio-methane component (at 60 per cent proportion)	0.97×10^9 m^3/annum
(c)	Methane energy content at 100 per cent conversion efficiency=9.9 kW h/m^3 (Werner et al. [57]); total energy content (= oxidized − unburned)	9.5×10^9 kW h
(d)	Considering generator efficiency put at 30 per cent (=3 kW h/m^3 of bio-methane); electricity production	2.90×10^9 kW h/annum
(e)	CO_2 emissions from bio-methane combustion	1.78×10^6 t/annum
(f)	Unburned bio-methane losses into the atmosphere (methane being 23 times more potent than CO_2 according to Ghafoori et al. [45] and Melikoglu [40])	0.14×10^6 t CO_2 equivalent/annum
(g)	Amount of diesel fuel required to produce 2.9×10^9 kW h of electricity	0.97×10^9 l
(h)	CO_2 emissions arising from diesel fuel combustion	2.52×10^6 t
(i)	CO_2 emissions avoided due to fuel switching $[h-(e+f)]$	0.60×10^6 t/annum

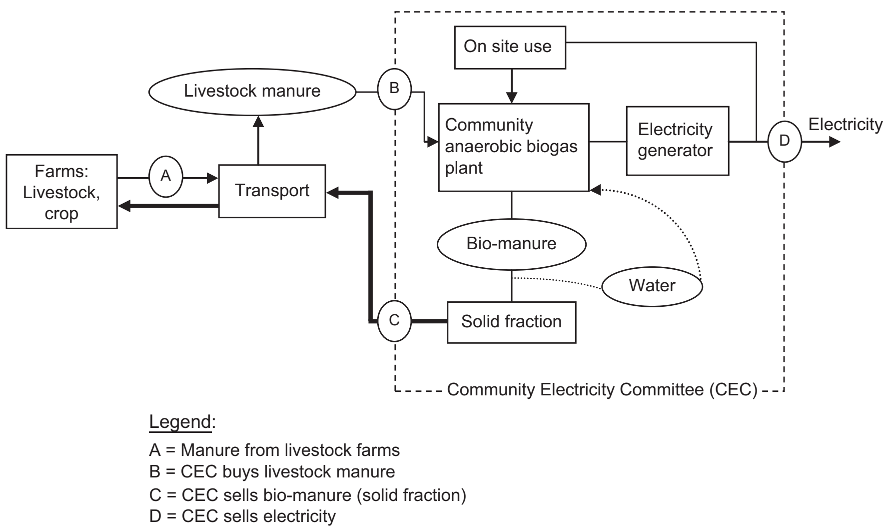


Fig. 1. The schematic illustration of the community biogas–electricity model.

growth, yield, quality, and soil fertility, the amount of inorganic nitrogen that will be replaced in the case of Nigeria translates to 38,000 t. Since between 5 and 10 per cent of the total volume of mixture in a digester is converted to gas [57], the minimum total amount of liquid bio-manure expected from the digester is about 86×10^6 t per annum or 7.7×10^6 t per annum at 10 per cent solids. At a minimum average of 0.5 per cent nitrogen content in total solids, the total amount of organic nitrogen is 38,700 t. This estimate is slightly higher than the amount needed to replace 38,000 t of inorganic nitrogen fertilizers. On the average, according to Kongshaug [65], about 2.2 t of CO_2 will be emitted by ammonia plants in the production of one tonne of inorganic nitrogen fertilizer. In the case of Nigeria, since 38,000 t of inorganic nitrogen fertilizer will be replaced by organic nitrogen fertilizer, this suggests that about 83,600 t of CO_2 emissions will be avoided per year (although these avoided emissions will be in the fertilizer producing countries). In total, the minimum climate value of biogas derived from livestock manure to meet electricity production and agricultural use in Nigeria translates to 683,600 t of CO_2 per annum.

4. The challenges

According to the World Bank [8], there is no electricity production plant from renewable energy sources (excluding hydroelectric) in Nigeria. And there is also a lack of data on the number of biogas digesters-in-use in Nigeria (compared to about 111,000 biogas plants in Nepal as of 2003 [50], over 1000 biogas digesters in Tanzania as of 2007 [47], 26.5 million biogas plants in China as of 2007 [30] or about 38.51 million household biogas plants as of 2010 [44], over 600 anaerobic digesters in Austria as of 2011 [32], and about 178 biogas power plants in Poland as of 2012 [38]). Although electricity production from livestock manure holds a great potential for Nigeria, the recovery of livestock manure poses a major challenge towards its realization. The majority of the domestic livestock is reared under the extensive livestock farming and pastoral systems, while a few other ones are reared under the intensive or semi-intensive livestock farming system (e.g., poultry layers, broilers, and some cockerels). As Lapp et al. [29] put it, the potential for manure recovery is enhanced by intensive livestock farming systems where large quantities of livestock dung accumulate rapidly. To achieve a sustainable manure recovery in Nigeria will require considerable investments in livestock housing. Another foreseeable limiting factor is the initial investment cost of biogas digesters (see, also Bond and Templeton [30]) considering the poverty condition in Nigeria. As of 2010, about 61.2 per cent of the total population (or about 99.76 million people) was estimated to be living under a (US) dollar per day [69]. This indicates that their ability to afford biogas plants could be limited. However, this situation can be improved if the construction of community biogas digesters is encouraged. Under this arrangement (see Fig. 1), a Community Electricity Committee (CEC) can be put in

place. With financial assistance from the Local Government Authorities (e.g., financial support was also provided by the Chinese Government to promote the development of biogas in China [44]); the Committee could embark on the construction of a community biogas plant. After construction, the committee could be saddled with the responsibility of buying livestock manure and selling electricity and bio-manure to community members at reasonable prices, and also see to the operation and maintenance of the system. However, the extent to which this suggestion can be implemented in Nigeria is rather unknown. But as this paper agrees with IPCC [4], if energy supply from renewable sources is implemented, they are capable of contributing to socio-economic development, and to a reduction in the negative impacts of energy provision on the environment and human health. This also is in agreement with the view of Esfandiari et al. [31], Ishola et al. [47] and Holm-Nielsen et al. [12]. Although investment in biogas electricity is seen to be profitable (see, e.g., Golusin et al. [70], as in the case of Serbia), a profitability analysis would have to be conducted in the case of Nigeria to determine its level of financial attractiveness.

In brief, this paper has shown that generating biogas from livestock manure for electricity and agricultural use in Nigeria has a climate value. It illustrates this by showing that replacing diesel fuel with bio-methane and inorganic nitrogen fertilizer with organic nitrogen fertilizer from the anaerobic digester could save about 683,600 t of CO_2 or about 0.97×10^9 l of diesel fuel on an annual basis. Two major challenges have been identified in this paper which can possibly limit the realization of these potential benefits in the case of Nigeria. They are (a) livestock manure recovery, and (b) poverty issues in Nigeria. While the former requires a considerable investment in livestock housing to mitigate, the latter can be ameliorated if the construction of community biogas systems is encouraged. This suggestion, though novel in the case of Nigeria, if implemented based on appropriate financial incentives designed to encourage the purchase of livestock manure from farmers, has an indirect advantage of encouraging improved livestock manure recovery in Nigeria.

5. Conclusions and recommendations

This paper contributes to the growing literature on climate change mitigation from a renewable energy perspective. It reveals that switching from fossil fuel and inorganic nitrogen fertilizer to bio-methane for electricity production and organic nitrogen fertilizer for agricultural use could contribute to lowering global greenhouse gas emissions. In the case of Nigeria, about 683,600 t of CO_2 could be saved per annum, although some of these savings, which correspond to 83,600 t of CO_2, will be in the inorganic fertilizer producing countries. However, under the present livestock farming and socio-economic conditions in Nigeria, the realization of these benefits can be constrained by two major factors as identified in the paper. They are (a) the problem of livestock manure recovery, and (b) the poverty situation in Nigeria. To mitigate these limiting factors, this paper suggests that the construction of community biogas plants for electricity generation should be encouraged in Nigeria. This arrangement is expected to promote a sustainable manure recovery through livestock manure trading. Since the suggestion on biogas-electricity generation is novel in the case of Nigeria and coupled with the need to bring in the Local Government Authorities to provide financial assistance; this suggestion will require a legislative support to make it work. To realize this, the legal framework should mandate the Local Government Authorities, who by statute (e.g., as enabled by the 1999 Constitution of the Federal Republic of Nigeria) are the closest tier of government to the grass roots, to assist interested communities with the initial financial resources and guidance required to build and operate a community biogas plant for electricity generation. In this regard, the National Energy Policy of 2003, which will possibly inform future renewable and/or energy laws in Nigeria, should be amended to take up this additional task.

Lastly, it is suggested that this paper can be used as a reference in the assessment of biogas generation potential from other organic sources in Nigeria and elsewhere with a view to estimate their contribution to climate change mitigation or climate value.

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